Cooling Summer Daytime Temperatures in Coastal California During 1948-2005: Observations and Implications for Energy Demand

Prof. Robert Bornstein, Dept. of Meteorology
San Jose State University
pblmodel@hotmail.com
Prof. Jorge Gonzalez and Bereket Lebassi,
Dept. of Mechanical Engineering, Santa Clara U.
Dr. Haider Taha, Altostratus Inc., Martinez, CA
Prof. Paul Switzer, Dept. of Statistics, Stanford U.

Presented as the
5th CEC Climate Change Conference
8 Sept. 2008

Outline

- Introduction to research
  - team
  - topic
- Our coastal cooling analyses
  - Trends
  - Spatial patterns
- Needed future efforts re
  - extended analyses
  - downscaled modeling
  - coastal-cooling impacts

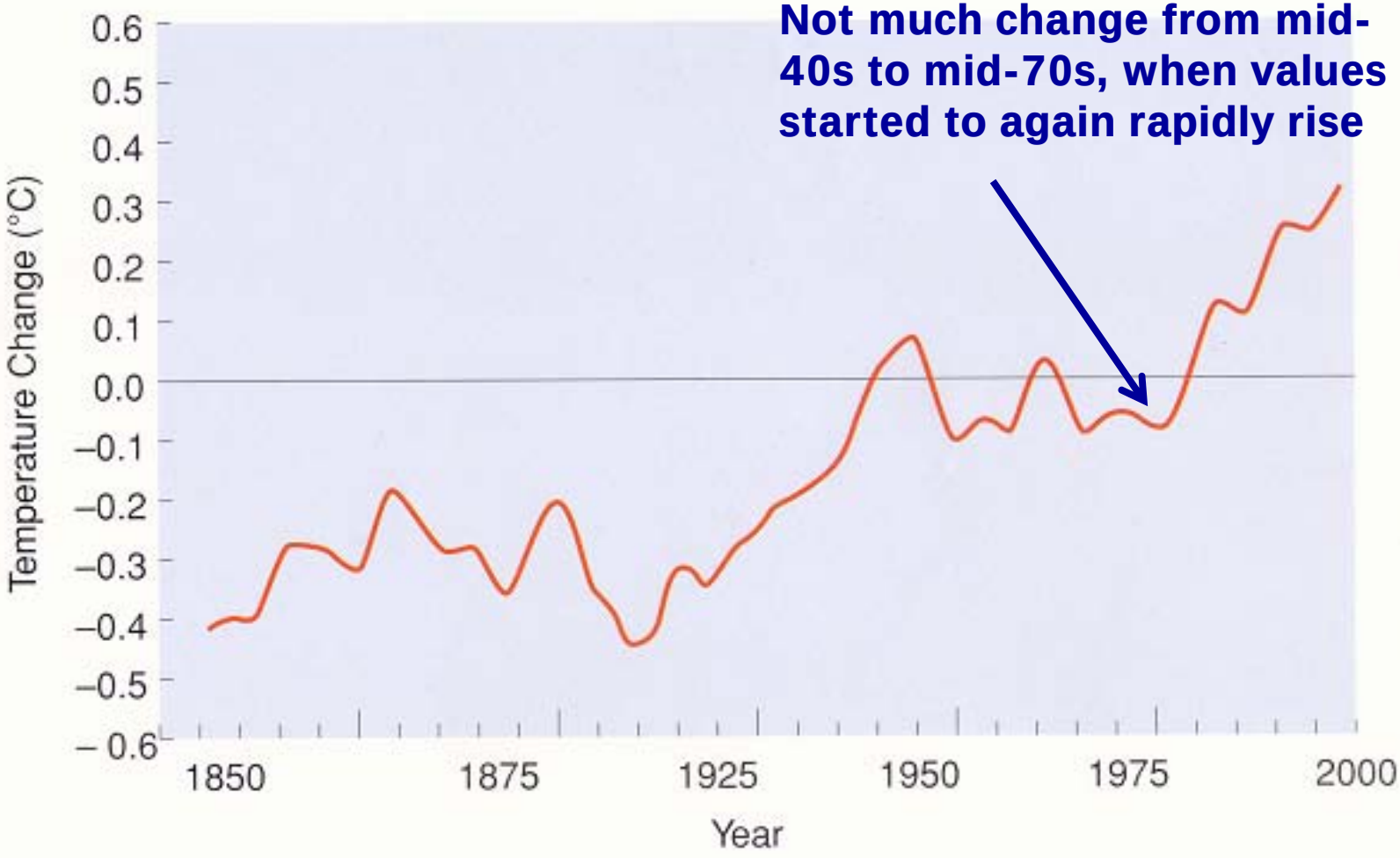
Background

- Global & CA observations generally show
  - asymmetric (more for T_{min} than for T_{max}) warming
  - that has accelerated since mid-1970s (see graph)
- CA downscaled global-modeling (see graph)
  - has been done (at SCU & elsewhere) onto 10 km grids
  - show summer warming that decreases towards coast (but no coastal cooling)

Transparency 99

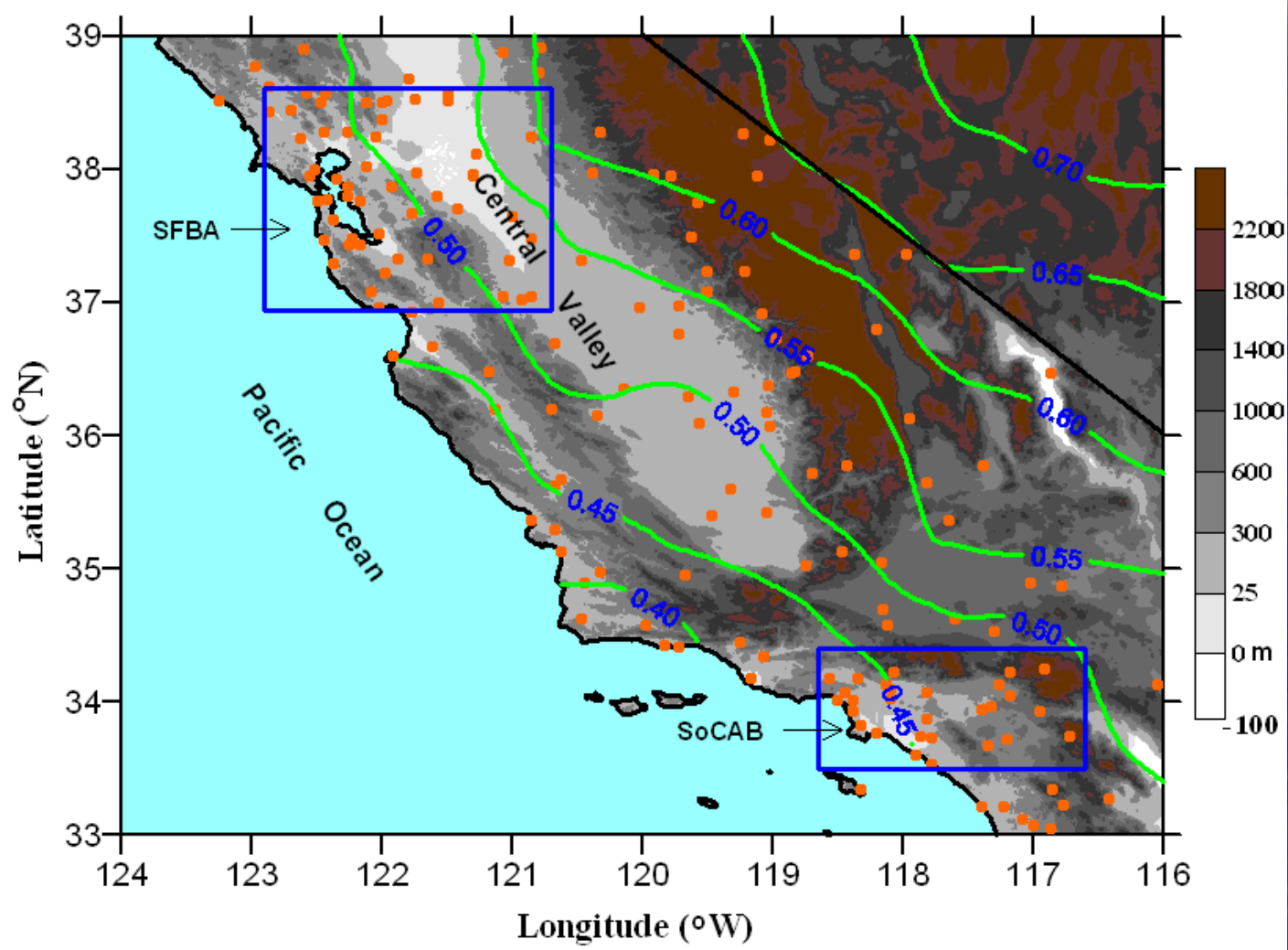
Figure 19.6

Changes in average global air temperature, 1861–1992



Not much change from mid-40s to mid-70s, when values started to again rapidly rise

Statistically down-scaled (Prof. Maurer, SCU) 1950-2000 annual summer (JJA) temp-changes (^{0}C) show warming rates that decrease towards coast, where red dots are COOP sites used in present study & boxes are study sub-areas



Climate-change (*=for CA) studies (next 2 slides) have discussed obs in terms of increased:

- SSTs & urbanization (*Goodridge '91, Karl et al. '93)
- Cloud cover (*Nemani et al. 2001)
- Coastal upwelling (*Bakum 1990; Snyder et al. 2003; McGregor et al. 2007)
- Land-cover conversions (Chase et al. 2000; Mintz 1984; Zhang 1997)
- Irrigation (*Christy et al. '06; Kueppers et al. '07, Bonfils & Duffy '07, *Lobell & Bonfils et al. '08)
- Solar absorption (Stenchikov & Robock 1995)

Publication	Parameter Studied	Finding
Goodridge (1991)	80 years of annual-average daily T_{ave} at 112 site	Warming in both coastal (attributed to warming SSTs) & inland urban (attributed to UHI effects) areas; cooling in inland rural areas was unexplained
Nemani et al. (2001)	Sites in Napa & Son-oma Valleys during 1951-97 for T_{min} & T_{max}	T_{min} increased & T_{max} slightly decreased, both attributed to measured increased cloud cover. Increased annual coastal T_D related to increased SSTs
Duffy et al. (2006)	Interpolated (to grid) monthly-average T_{ave} from 1950-99	Warming in all seasons, attributed to increased UHIs or GHGs
Christy et al. (2006)	18 Central Valley sites from 1910-2003 for T_{ave} T_{max}, & T_{min}	Increased T_{ave} & T_{min} in all seasons, greater in summer & fall. Summer cooling T_{max} & warming T_D values attributed to increased summer irrigation

Bonfils & Duffy (2007)	Christy et al. (2006) T_{min}	Warming T_{min} not due to irri-gation, which could only overcome GHG-warming for T_{max}
Bonfils & Lobell (2007) and Lobell & Bonfils (2008)	Gridded T_{max} & T_{min}	Expanded irrigation cooled sum-mer T_{max}, while producing negli-gible effects on T_{min}
LaDochy et al. (2007)	331 sites during 1950-2000 for T_{ave}, T_{min}, & T_{max}	Annual T_{ave} warming at most sites. Almost all increases due to changes in T_{min} (max in sum-mer), as T_{max} showed no change or cooling. Max T_{ave} warming in southern CA, but NE Interior Basin showed cooling
Abatzoglou et al. (2008)	Coastal sites during 1970-2000 for T_{max}	Significant coastal cooling in late summer & early fall

The Current Hypothesis

INCREASED GHG-INDUCED INLAND TEMPS→

INCREASED (COAST TO INLAND) PRESSURE & TEMP GRADIENTS→

INCREASED SEA BREEZE FREQ, INTENSITY, PENETRATION, &/OR DURATION →

COASTAL AREAS SHOULD SHOW COOLING SUMMER DAYTIME MAX TEMPS (i.e., A REVERSE REACTION)

NOTE:

NOT A TOTALLY ORIGINAL IDEA →

A9 ★★★★ San Francisco Chronicle

How S.F. Could Get Even Foggier

'Greenhouse Effect' Could Backfire

By Charles Petit
Chronicle Science Writer

Notions that global warming from the "greenhouse effect" might bring balmy summers to San Francisco beaches got a dash of cold water this week.

A government oceanographer says a warmer Earth will make it even colder and foggier along Northern California's coast and that the trend may already have started here and in similar coastal regions in Spain, Morocco and Peru.

Hotter weather in the Central Valley might mean higher winds along the coast. The wind would stimulate upwelling of the cold water and onshore breezes that make the region's famous fogs, reports Andrew Bakun in today's issue of the journal Science.

Bakun is a physical oceanographer and chief of the Pacific Fisheries Environmental Group, a 12-person research laboratory operated by the National Oceanic and Atmospheric Administration in Monterey.

In an interview, Bakun emphasized that his projection cannot calculate just how much foggier it may get. He also said he could easily turn out to be wrong — just as widely accepted predictions that the Earth on average will warm by 3 to 9 degrees Fahrenheit in the next century may also turn out wrong.

But, he said, the main point is that even if the greenhouse scenario is correct for the planet on average, "it is a mistake to think that means it will warm up everywhere. There are very good reasons to think it will be colder here, at least in summer."

He also suspects that the summer fog season would start earlier in the season and end later.

Summer fog streams regularly across California's coast, most intensely between Point Conception northward into Oregon, because of several factors.

The chief ones are upwellings of deep, cold ocean water to the surface along the shore and breezes that draw relatively warm, humid air inland. The combination of chilling from the upwelling water, and land that forces the air upward, causes fog to condense from the air.

Although measurements are not precise, data suggest that winds have already started picking up along California's coast. Studies of wind stress — the amount that winds push surface currents — show a roughly upward trend since about 1945. This is during a time that some climatologists believe they have detected a slight warming of the Earth. Similar trends appear under way off the coasts of Peru, Spain and Morocco where local fog conditions resemble those of Northern California.

Upwelling causes both the frigid swimming conditions along Northern California's beaches, as well as the good fishing. The deep waters carry nutrients that support much of the shallow marine life of California.

A fisheries specialists, Ba... not sure that more intense u... ing would improve fishing. "... would be more nutrients, bu... will also have more rapid exp... these nutrients offshore, and ... wind means more turbulence.

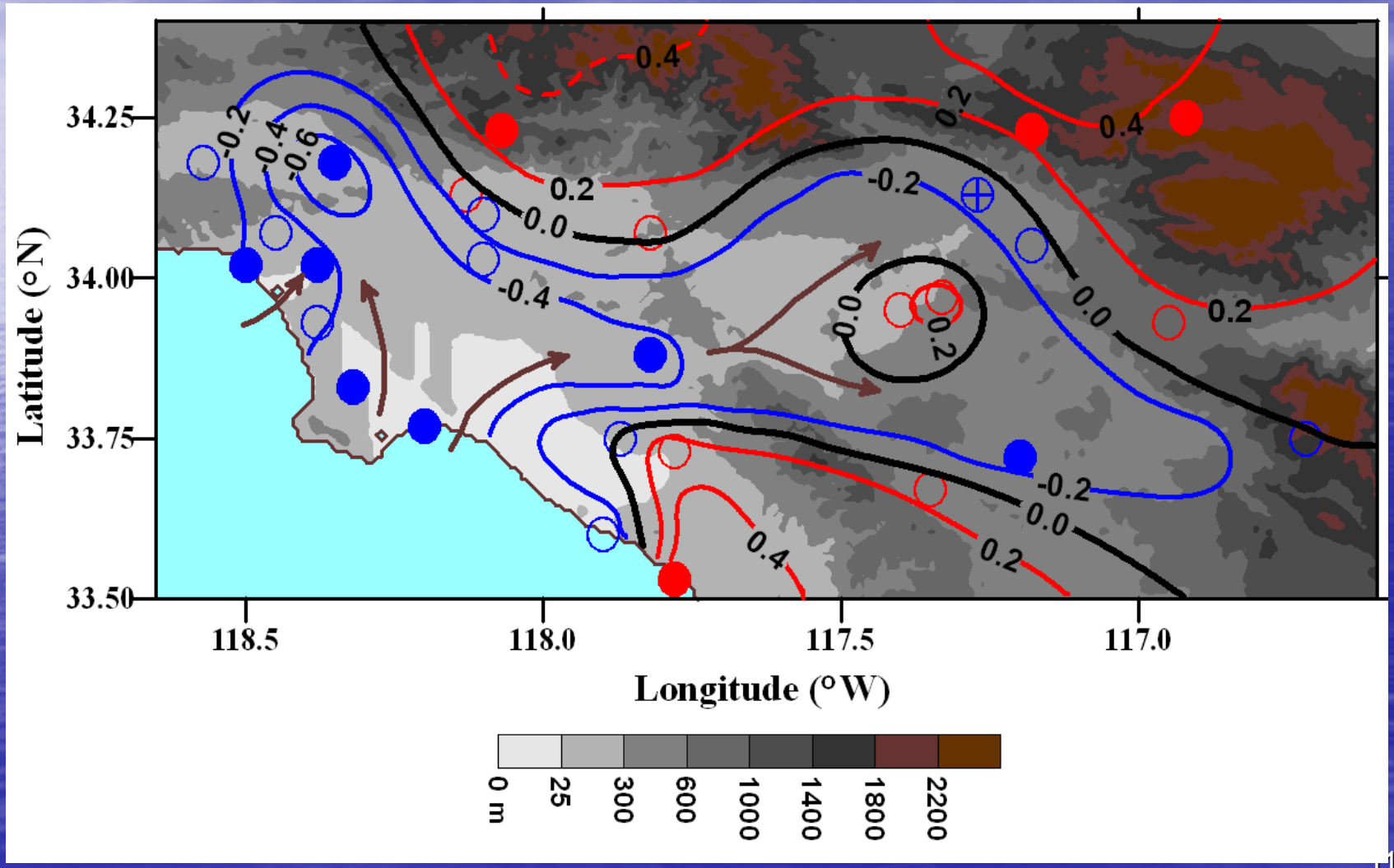
WHY 'GREENHOUSE EFFECT' MAY MEAN MORE COASTAL FOG

Heat in the Central Valley creates a weather cycle that promotes fog along the coast, which drifts inland and cools things down. If the "greenhouse effect" makes the Central Valley hotter, the whole process could produce more fog.

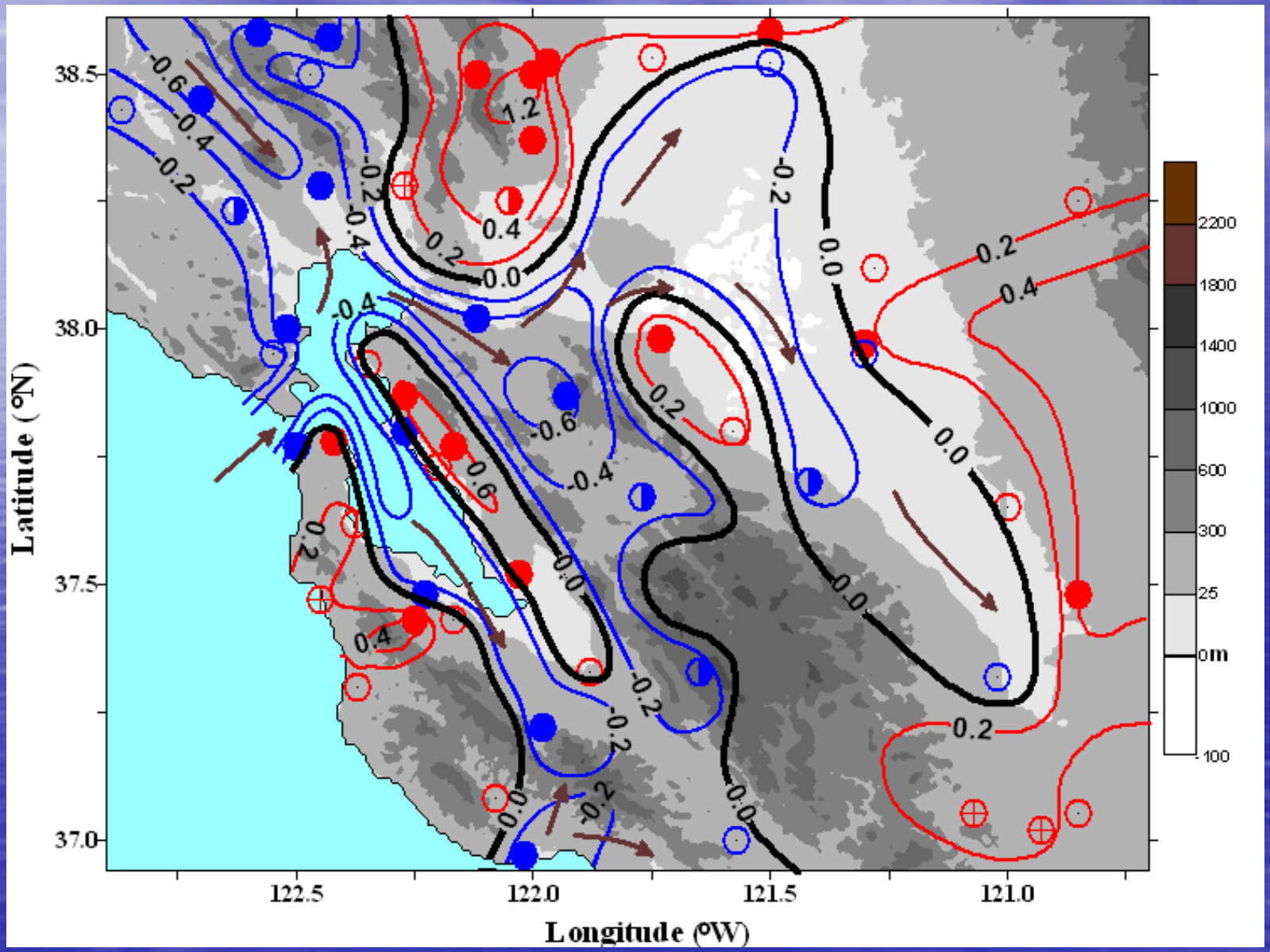
CURRENT DATA

- NCDC DAILY MAX & MIN 2-METER TEMPS
  - FROM ABOUT 300 CA NWS COOP SITES (SEE MAP)
  - FOR 1948-2005
  - HAVE BEEN USED IN MANY OTHER CA CLIMATE-CHANGE STUDIES
- NCDC MEAN MONTHLY GRIDDED SEA SURFACE TEMPS (SSTs)
  - FROM INTERNATIONAL COMPREHENSIVE 0CEAN-ATM DATA SET (ICOADS)
  - AT 2-DEG HORIZ RESOLUTION
  - FOR 1880-2004
- NWS 1600-LST DEW-POINT TEMPS
  - FROM TWO NWS AIRPORT SITES: COASTAL-SFO & INLAND-SAC
  - FOR 1970-2005
- ERA40 1.4 DEG REANALYSIS 1000-LST SUMMER T-85
  - SEA-LEVEL PRESSURE CHANGES
  - FOR 1970-2005

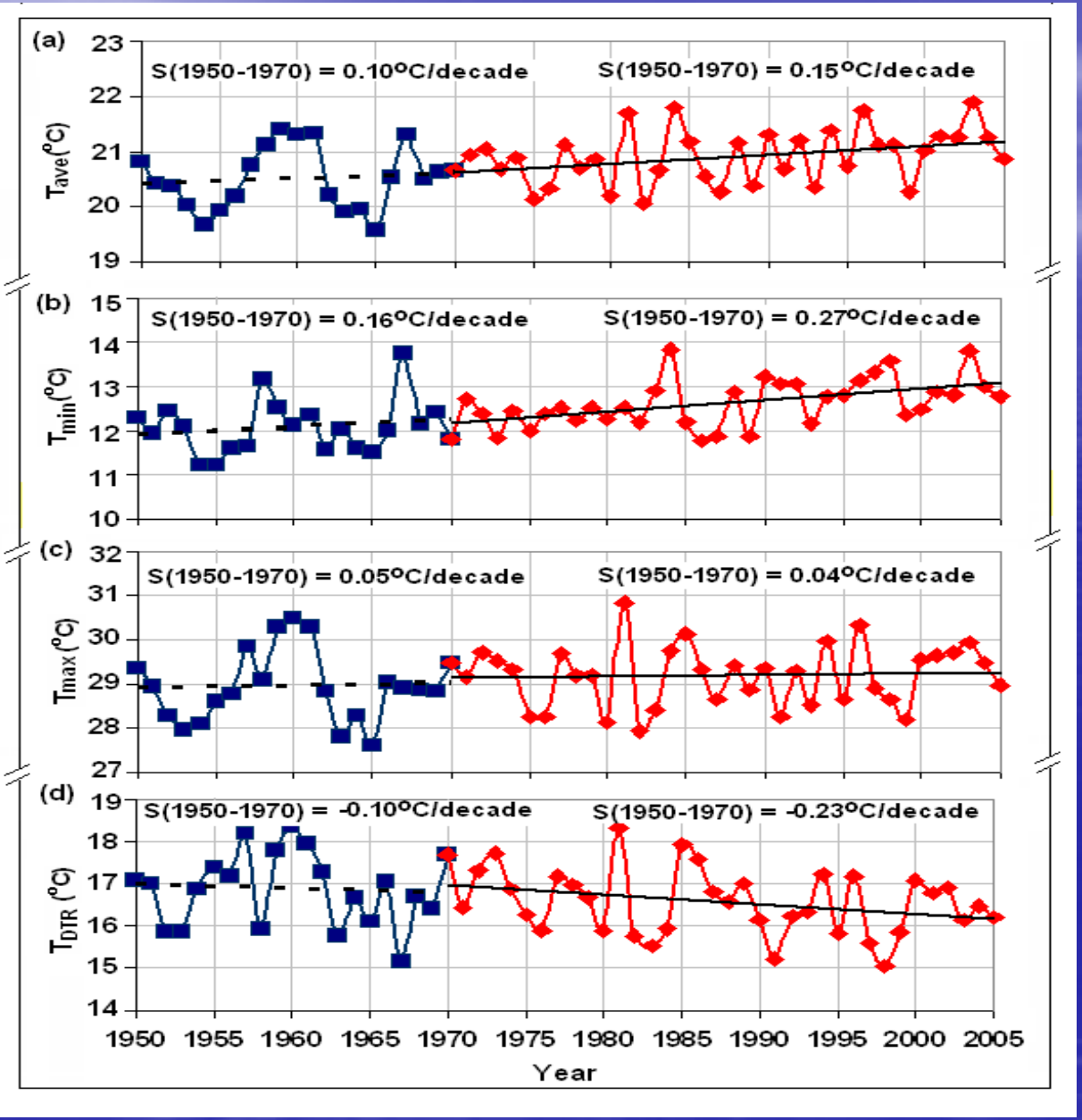
Results 1: SoCAB 1970-2005 summer (JJA) T_{max} warming/cooling trends (^{0}C/decade); solid, crossed, & open circles show stat p-values < 0.01, 0.05, & not significant, respectively



Results 2: SFBA & CV 1970-2005 JJA T_{max} warming/cooling trends (^{0}C/decade), as in previous figure

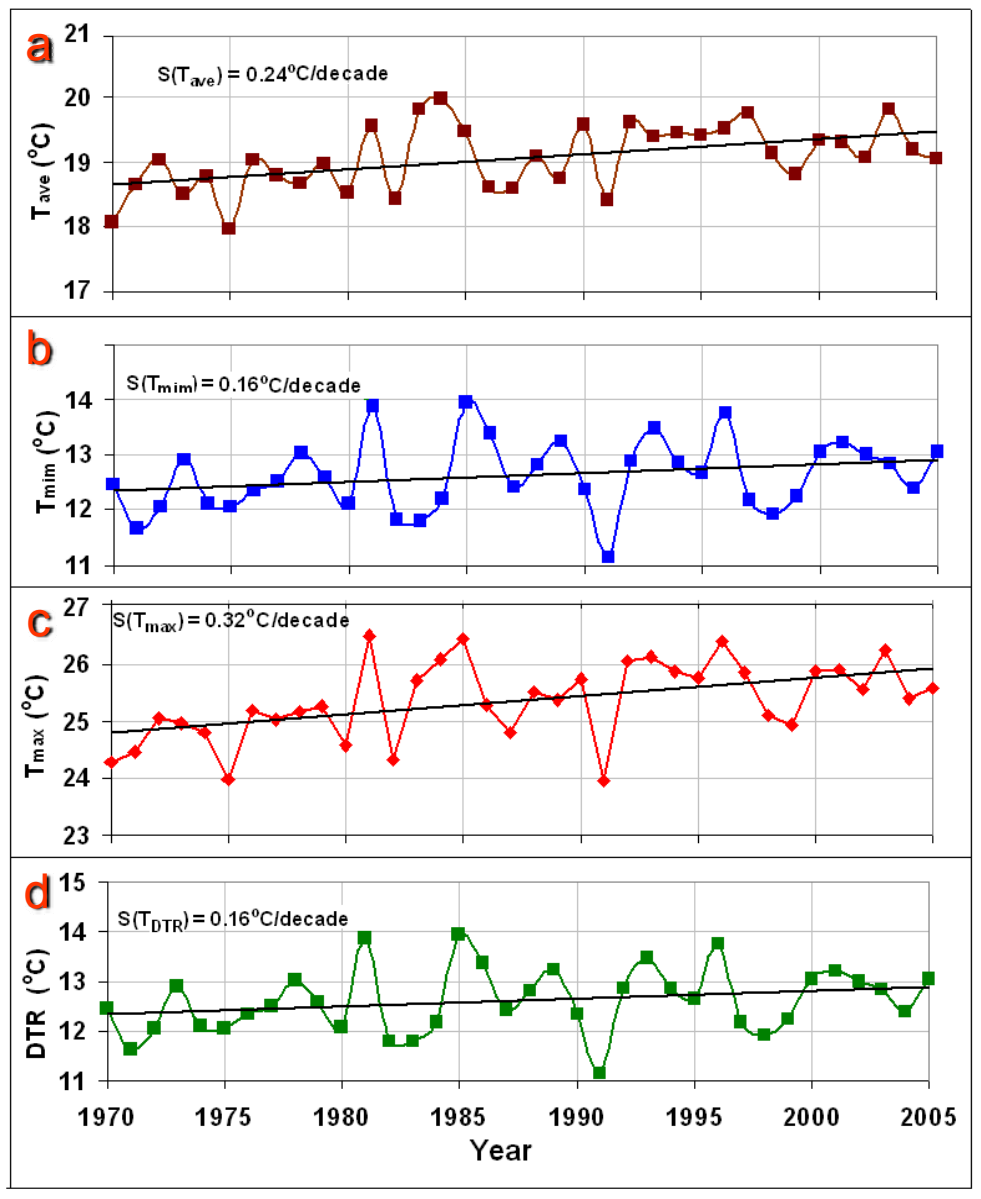


Results 3: JJA Temp trends; all CA-sites



- LOWER TRENDS FROM 1950- 70 (EXCEPT FOR T_{MAX})
- Curve b: T_{MIN} HAD FASTEST RISE (AS EXPECTED)
- Curve c: T_{MAX} HAD SLOWEST RISE; IT IS A SMALL-Δ B/T BIG POS VALUE & BIG NEG-VALUE (AS ABOVE)
- CURVE a: T_{AVE} THUS ROSE AT MID RATE
- Curve d: DTR THUS DECREASED (AS T_{MAX} FALLS & T_{MIN} RISES)

Result 4: JJA T_{ave}, T_{min}, T_{max}, & DTR TRENDS FOR INLAND-WARMING SITES OF SoCAB & SFBA



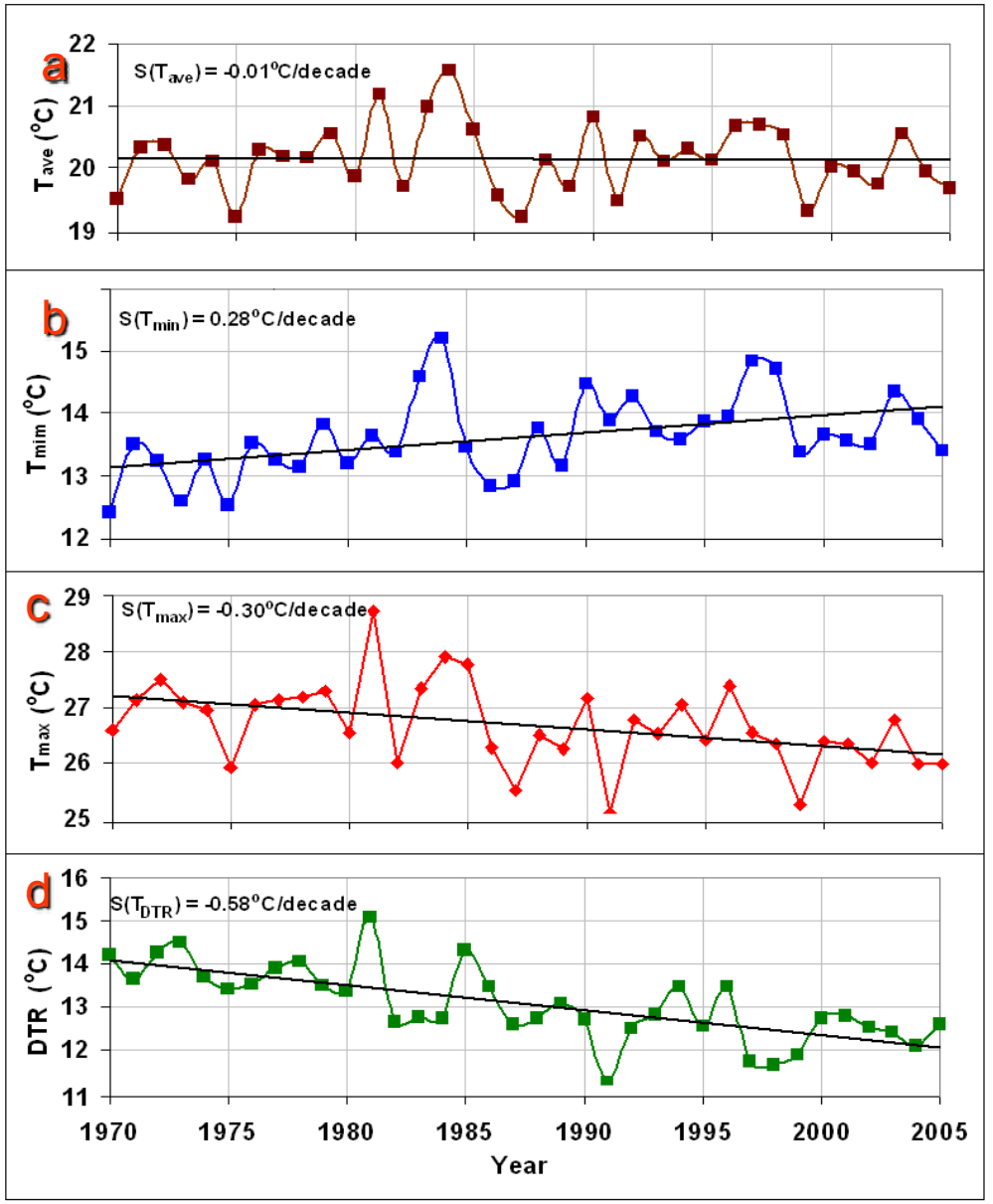
Curve b: T_{MIN} INCREASED (EXPECTED)

Curve c: T_{MAX} HAD FASTER RISE; (UNEXPECTED), COULD BE DUE TO INCREASED UHIs

CURVE a: T_{AVE} THUS ROSE AT MID RATE

Curve d: DTR THUS INCREASED (AS T_{MAX} ROSE FASTER THAN T_{MIN} ROSE

Result 5: JJA T_{ave}, T_{min}, T_{max}, & DTR TRENDS FOR COASTAL-COOLING SITES OF SoCAB & SFBA



Curve b: T_{MIN} ROSE (EXPECTED)

Curve c: T_{MAX} HAD COOLING (UNEXPECTED MAJOR RESULT OF STUDY)

CURVE a: T_{AVE} THUS SHOWED ALMOST NO CHANGE, AS FOUND IN LIT.), AS RISING T_{min} & FALLING T_{max} CHANGES ALMOST CANCELLED OUT

Curve d: DTR THUS DECREASED, AS T_{MIN} ROSE & T_{MAX} FELL

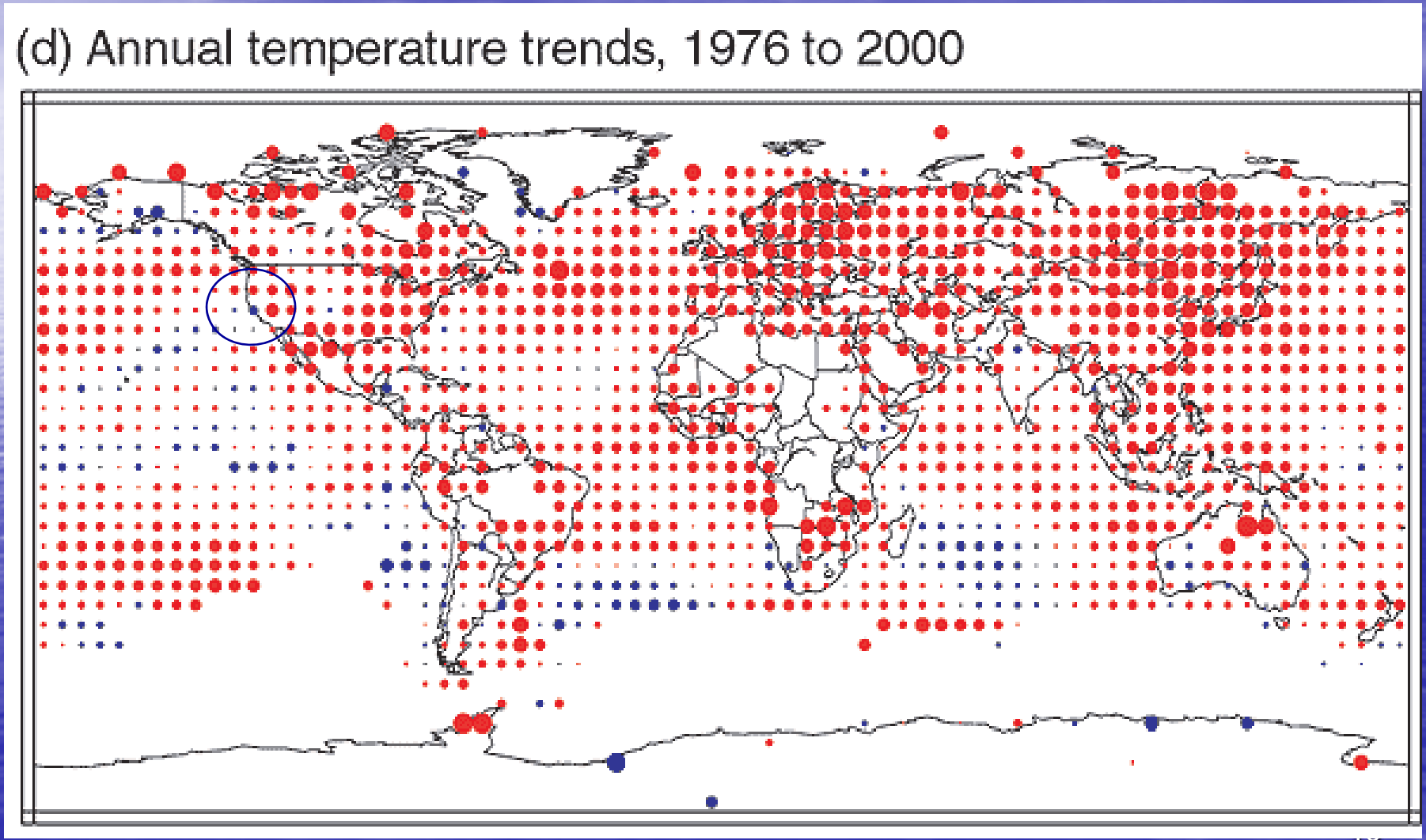
Current coastal-cooling results are unique because study is first to:

- divide obs. in all the following ways
  - summer (JJA)-values only
  - T_{max} & T_{min}, as well as T_{ave}-values
  - coastal vs. inland sites
- consider sea-breeze enhancement as a causal mechanism, instead of: GHGs, irrigation, SST, UHI, PDO, &/or aerosols (lit review slides, above)
- carry out data analyses and meso-met modeling (next section)

SUMMARY OF CURRENT CA OBS

- SUMMER MIN-TEMPS IN CALIF HAVE BEEN WARMING FASTER THAN MAX-TEMPS
- SUMMER DAYTIME MAX-TEMPS HAVE BEEN COOLING, BUT ONLY IN LOW-ELEVATION COASTAL AIR- BASINS
- FOLLOWING AREAS ARE COOLING IN CENTRAL CA:
  - >MARINE LOWLANDS > MONTEREY
  - > SANTA CLARA & LIVERMORE VALLIES
  - > WESTERN SACRAMENTO VALLEY
- CURRENT OBS ARE, HOWEVER, CONSISTENT WITH (BUT ARE MORE DETAILED & FOCUSED) THAN
  - CA-COOP LIT-RESULTS (PREVIOUS SLIDES)
  - IPCC GLOBAL OBS (NEXT SLIDE)

Note: note IPCC 2001 cooling over SFBA!!



OUR GROUP'S MESO-MODELING EXPERIENCE

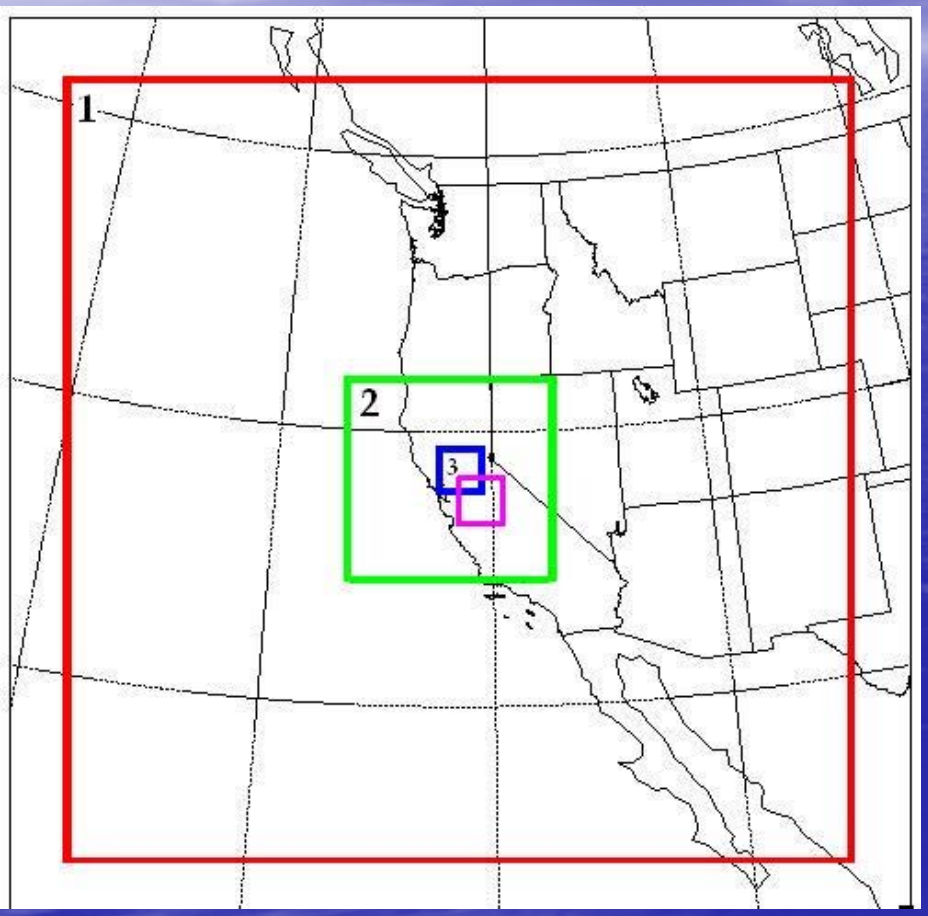
- SJSU (MM5 & uMM5)
  - Lozej (1999) MS: SFBA winter wave cyclone
  - Craig (2002) MS: Atlanta UHI-initiated thunderstorm (NASA)
  - Lebassi (2005) MS: Monterey sea breeze (LBNL)
  - Ghidey (2005) MS: SFBA/CV CCOS episode (LBNL)
  - Boucouvula (2006a,b) Ph.D.: SCOS96 episode (CARB)
  - Balmori (2006) MS: Tx2000 Houston UHI (TECQ)
  - Weinroth (2009) PostDoc: NYC-ER UDS urban-barrier effects (DHS)
- SCU (uRAMS)
  - Lebassi (2005): Sacramento UHI (SCU)
  - Lebassi (2009) Ph.D.: SFBA & SoCAB coastal-cooling (SCU)
  - Comarazamy (2009) Ph.D.: San Juan climate-change & UHI (NASA)
- Altostratus (uMM5 & CAMx)
  - SoCAB (1996, 2008): UHI & ozone (CEC)
  - Houston (2008): UHI & ozone (TECQ)
  - Central CA (2008): UHI & ozone (CEC)
  - Portland (current): UHI & ozone (NSF)
  - Sacramento (current): UHI & ozone (SMAQMD)
- 2009 = submitted for presentation at AMS national conf

LEBASSI Ph.D. (at SCU): RAMS MESO-MET SFBA & SoCAB Simulations

Run No.	Global CO_2 levels	Coastal SST values	LU/LC (Agriculture & Urban)	Notes on Conditions simulated
1	√	√	√	Total Current
2	√	√	o	Only Past-Global
3	o	o	√	Only Past-LU/LC
4	o	o	o	Total Past

where: o = pre-European- & √ = current-conditions

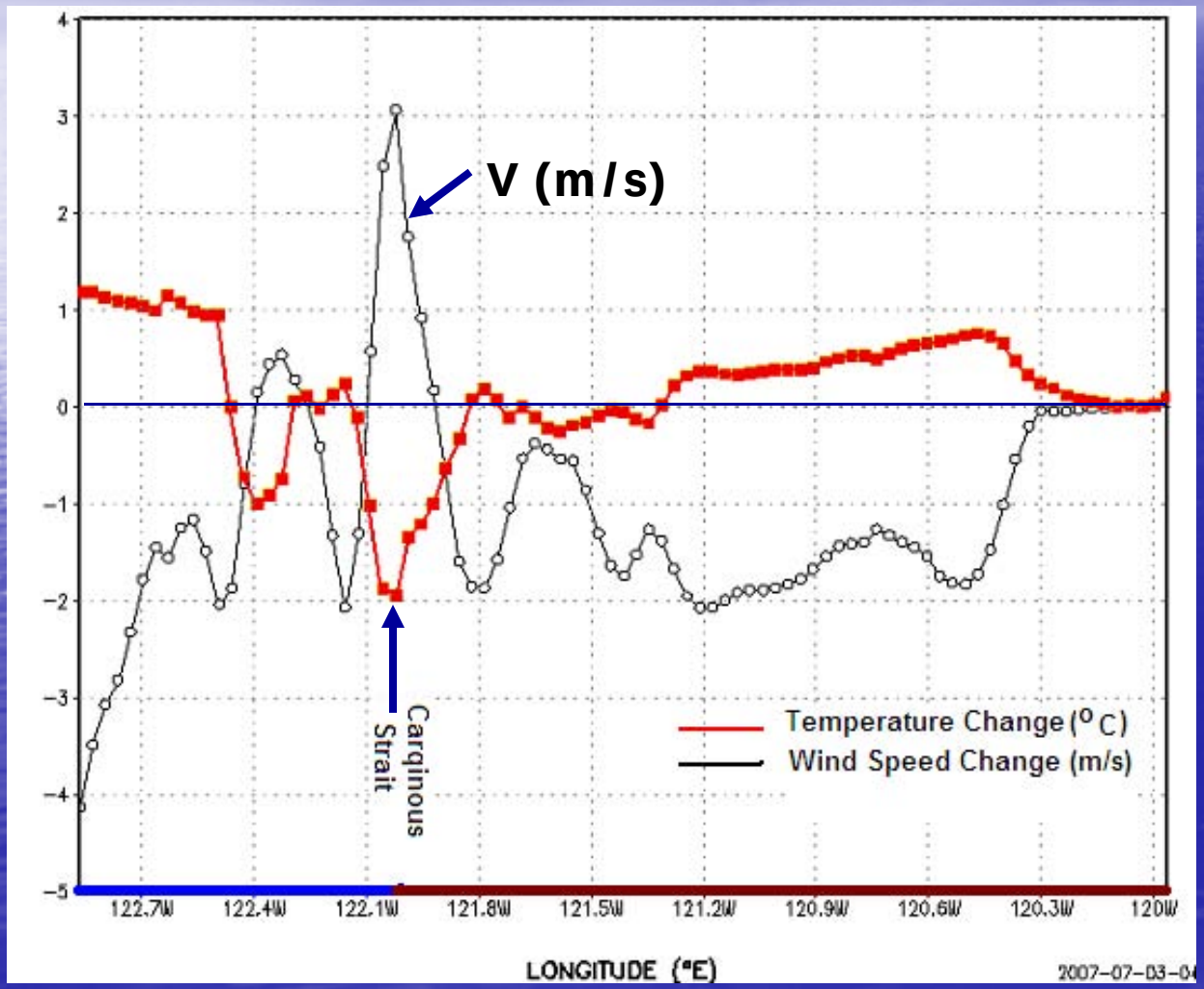
Rams Grid Configuration



- Horizontal Grid
  - Arakawa type C staggered grid
  - Three nested grids

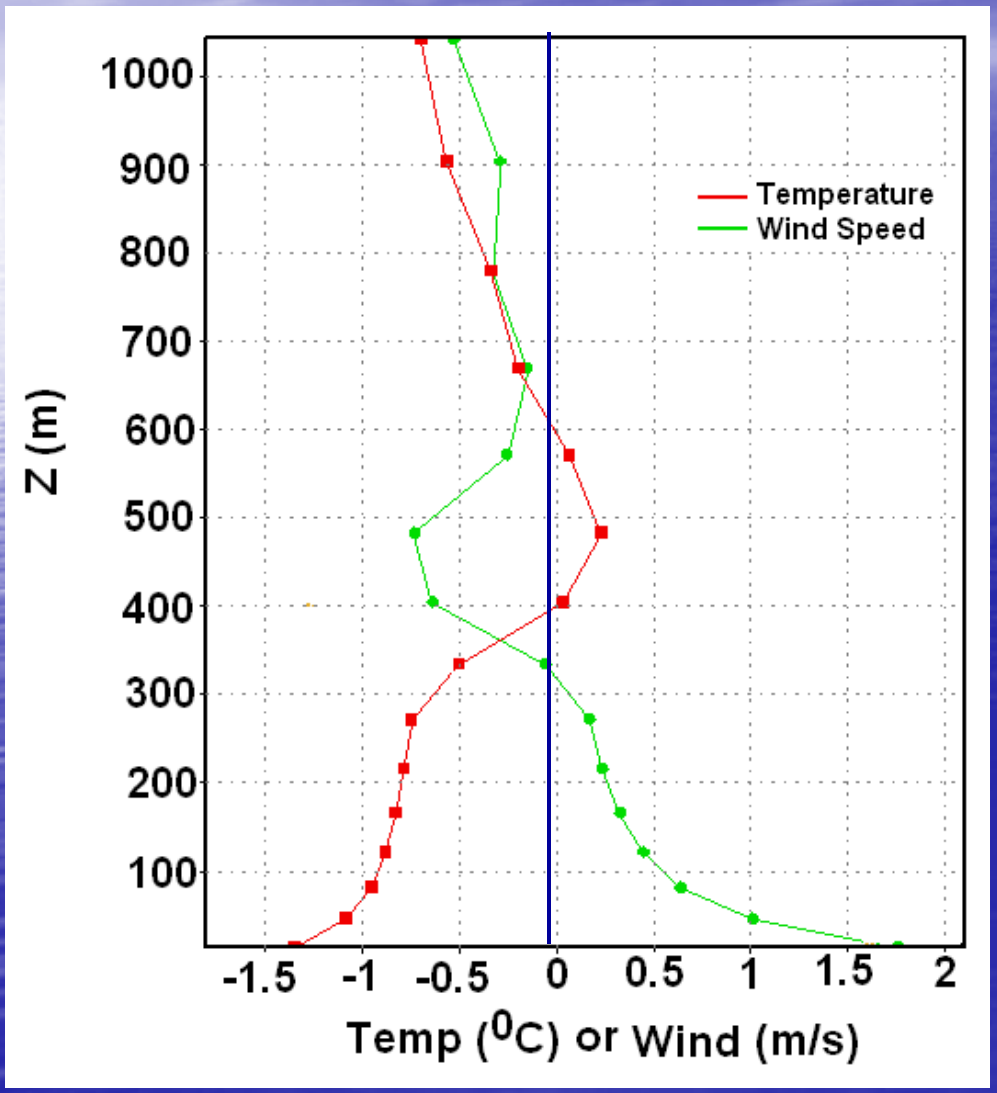
Grid	x	y	z	Δx ,Δy	Δz	Δt
1	80	80	50	60 Km	10m	10s
2	82	82	50	15 km	10m	5s
3	70	70	50	3.75 km	10m	2.5s

RAMS SFBA Result 1: Average July-2006, 4 PM changes (present minus past land-use; no GHG changes) in 2-m T (^{0}C) & 10-m V (m/s) in W-E plane thru Carquinez Strait



Land-use changes resulted in increased flow-rate of cool sea-breeze air thru the Strait

RAMS Result 2: Vertical profile of T (^{0}C) & V (m/s) changes at 4 PM at point with peak speed in Carquinez Strait (in previous slide)



Results show that increased sea-breeze air flow thru Strait (in previous slide) decreases with altitude & is capped by return-flow aloft (at 350-600 m AGL)

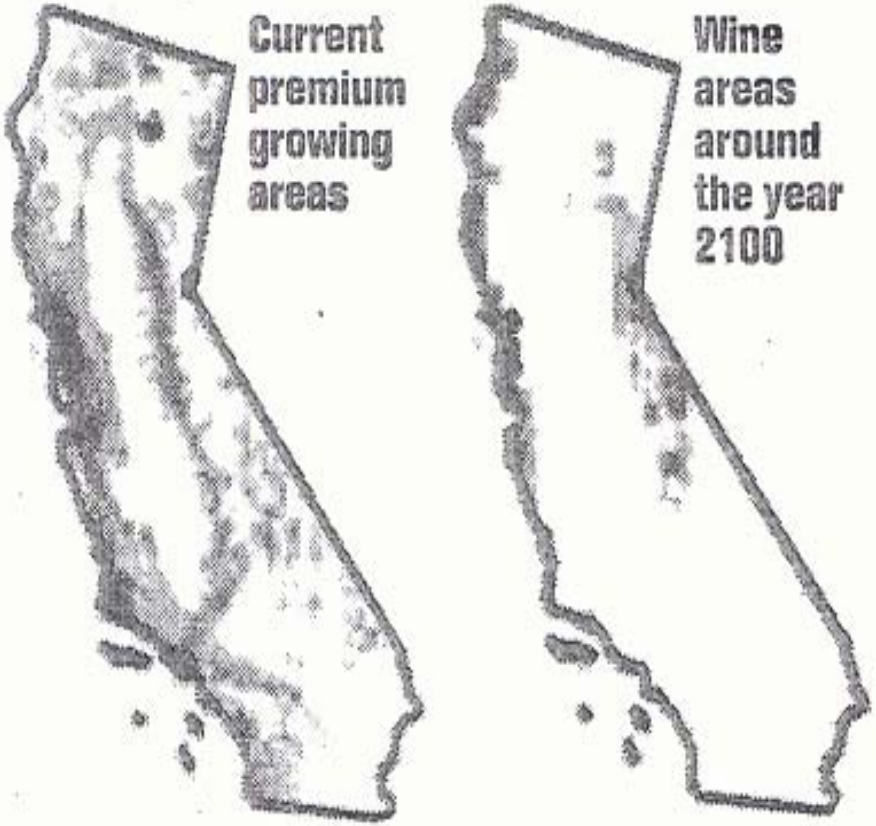
BENEFICIAL IMPLICATIONS OF COASTAL COOLING

- NAPA WINE AREAS MAY NOT GO EXTINCT (REALLY GOOD NEWS!; SEE MAP)
- LOWER HUMAN HEAT-STRESS RATES
- OZONE CONCENTRATIONS MIGHT CONTINUE TO DECREASE, AS LOWER MAX-TEMPS REDUCE
  - ANTHROPOGENIC EMISSIONS
  - BIOGENIC EMISSIONS
  - PHOTOLYSIS RATES
- ENERGY FOR COOLING MAY NOT INCREASE AS RAPIDLY AS POPULATION (4 SLIDES)

NAPA WINE AREAS MAY NOT GO EXTINCT DUE TO ALLEGED RISING T_{MAX} VALUES, AS PREDICTED IN NAS STUDY

Warming wine regions

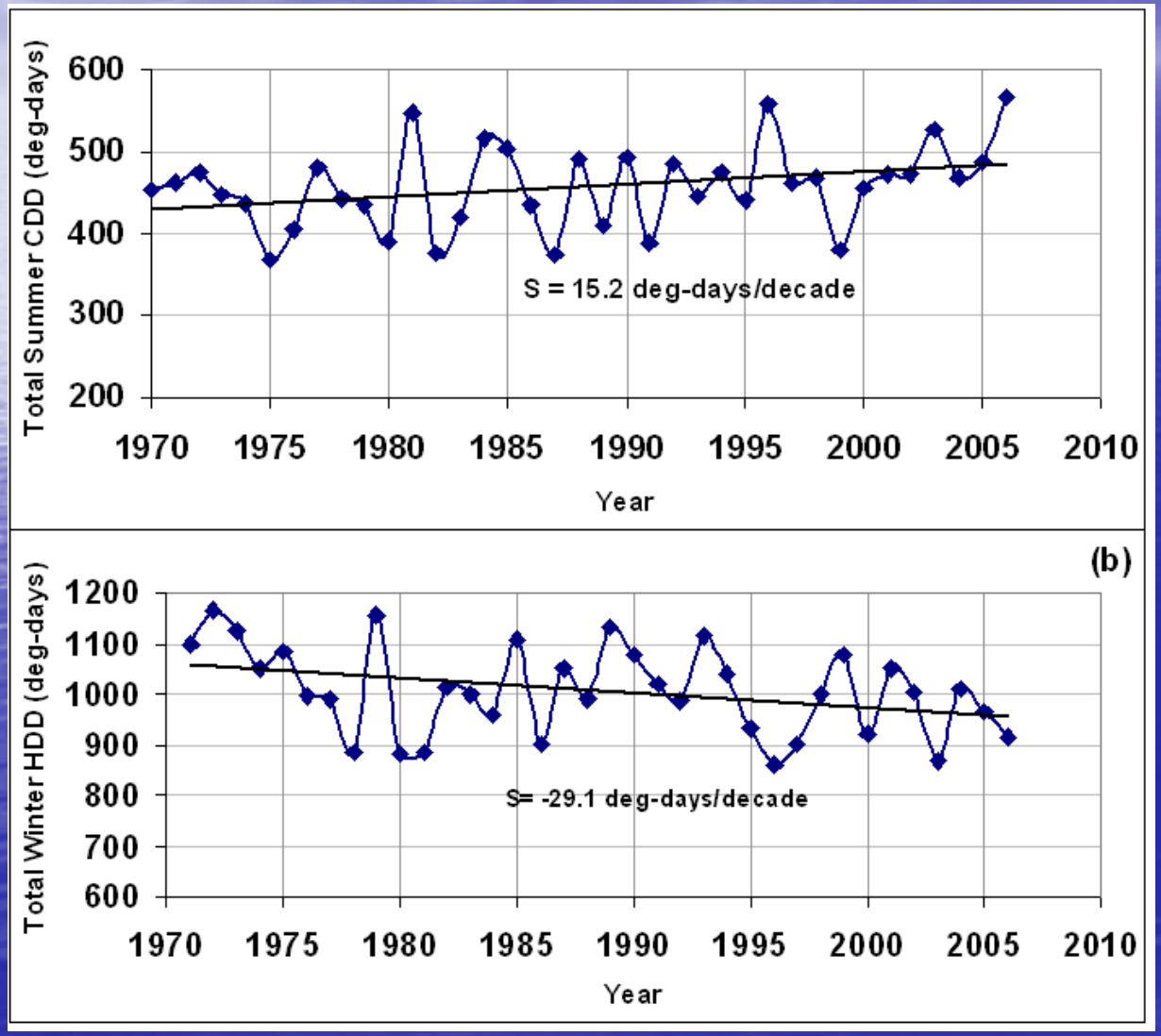
A new study out today suggests that global warming could drastically change which areas of the United States can grow premium wine grapes. By the end of the 21st century, the country could have lost 81 percent of its best and most reliable wine regions, including Napa and Sonoma.



Source: Proceedings of the National Academy of Sciences

The Chronicle

Implications for ALL-CA Energy Needs
Result 1: Heating Degree-(HDDs) & Cooling Degree- (CDDs) Days



CDDs

- INCREASED AT LOWER RATE, AS SUMMER MAX-T INCREASED AT A LOWER RATE

- NEED TO REDO THIS FOR COASTAL COOLING AREAS

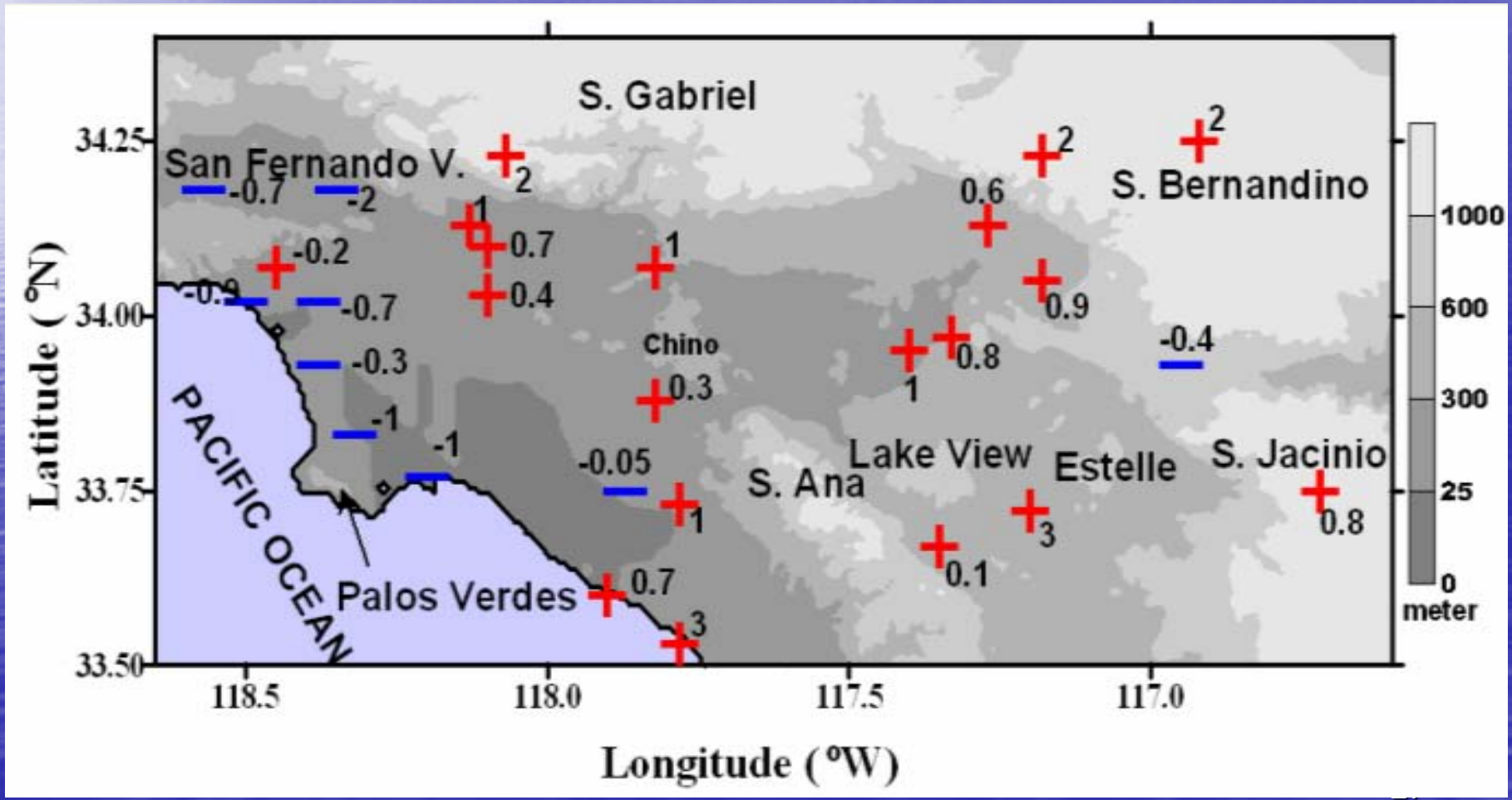
HDDs

- DECREASED AT FASTER RATE (WE DID NOT STUDY WINTER MIN-Ts)

Result 2: 1970-2005 SoCAB summer CCD-trends (degree-days/summer) generally shows:

> decreases in cooling coastal-areas

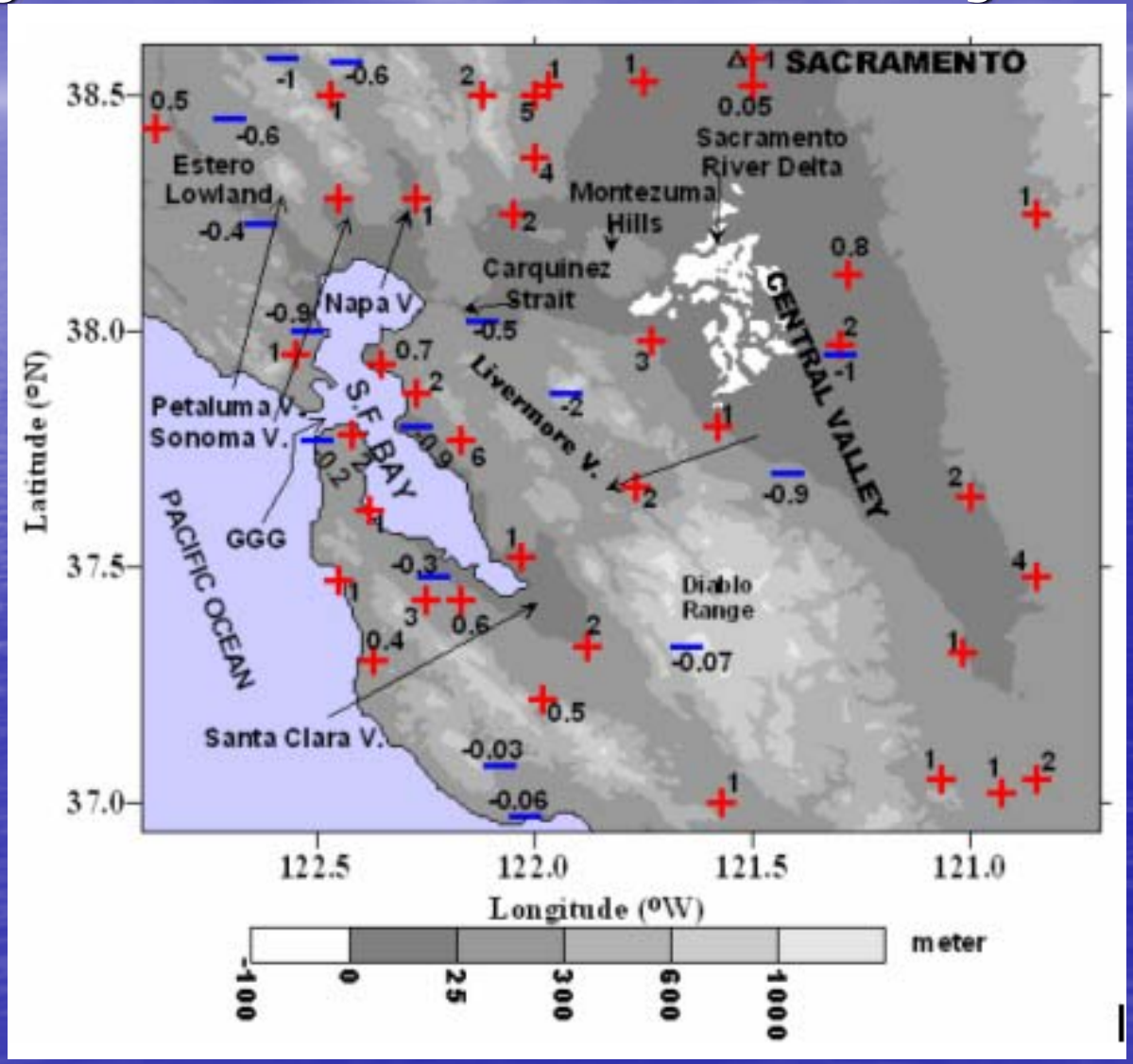
> increases in warming inland-areas



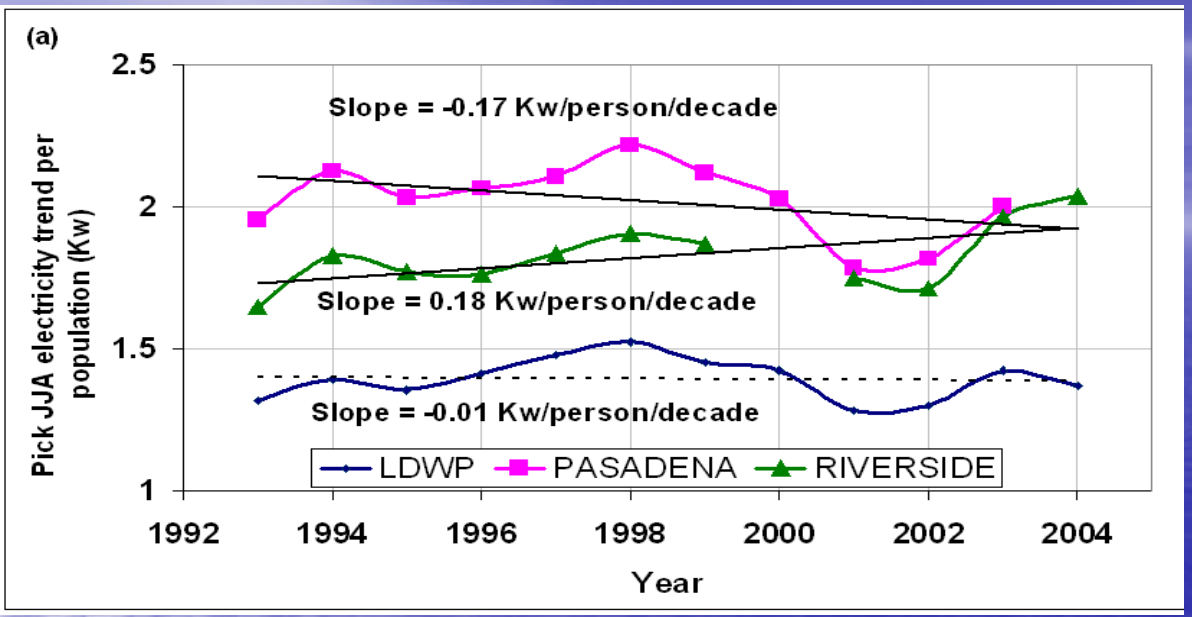
Result 3: SAME FOR SoCAB, generally shows

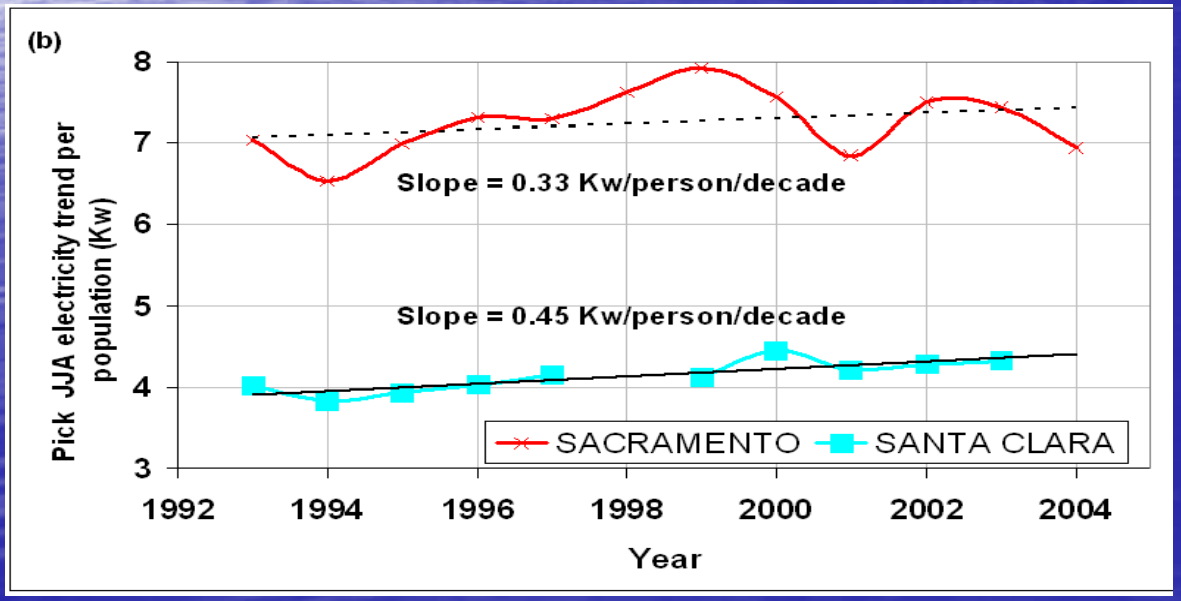
> decreases in cooling low-elevation coastal-areas

> increases high-elevation coastal-areas & warming inland-areas



Result 4: Peak-Summer Per-capita Electricity-Trends





➢ Down-trend at cooling coastal LA & Pasadena (pink line, 8.5%/decade)

> Up-trend at warming inland Riverside (green line)

> Up-trend at warming Sac & Santa Clara

> Need: detailed energy-use data for more sites

POSSIBLE FUTURE EFFORTS (PART 1 OF 2)

- EXPANDED (TO ALL OF CA)
  - ANALYSIS OF OBS (IN-SITU & GIS)
  - URBANIZED MESO-MET (MM5, RAMS, WRF) MODELING
- SEPARATE INFLUENCES OF CHANGING:
  - LAND-USE PATTERNS RE
    - AGRICULTURAL IRRIGATION
    - URBANIZATION & UHI-MAGNITUDE
  - SEA BREEZE:

    INTENSITY, FREQ, DURATION, &/OR PENETRATION
- DETERMINE POSSIBLE "SATURATION" OF SEA-BREEZE EFFECTS FROM
  - FLOW-VELOCITY & COLD-AIR TRANSPORT
  - AND/OR STRATUS-CLOUD EFFECTS ON LONG- & SHORT-WAVE RADIATION

POSSIBLE FUTURE EFFORTS (PART 2 OF 2)

- DETERMINE CUMULATIVE FREQ DISTRIBU-TIONS OF MAX-TEMP VALUES, AS
  - EVEN IF AVERAGE MAX-VALUES DECREASE,
  - EXTREME MAX-VALUES MAY STILL INCREASE (IN INTENSITY AND/OR FREQUENCY)
- DETERMINE CHANGES IN LARGE-SCALE ATMOSPHERIC FLOWS:
  - HOW DOES GLOBAL CLIMATE-CHANGE EFFECT POSITION & STRENGTH OF: PACIFIC HIGH & THERMAL LOW?
  - THIS IS ULTIMATE CAUSE OF CLIMATE-CHANGE

Conclusion

- Coastal-cooling of CA summer day-time max-temps needs consideration in future energy planning, along with changes in: population & efficiency
- The SJSU/SCU/Altostratus group
  - has deep experience in analysis & simulation of meso-scale met processes in California
  - can provide support to ongoing internal & external CEC efforts in climate downscaling & energy trend analyses
  - can downscale GCM-output down to grids of 1-5 km, so as to resolve CA coastal-topographic-urban influences
  - has existing CA efforts that could be leveraged by new CEC support

Thanks for listening!

Additional questions and discussion?